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DETERMINATION OF HALF-LIVES OF MAGNESIUM, ALUMINUM AND SILICON

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DETERMINATION OF HALF-LIVES
OF
MAGNESIUM, ALUMINUM AND SILICON

Lt. Harvey S. Henning, Jr., USN

A Thesis in Physics presented to the Faculty of the Graduate School of the University of Pennsylvania in partial fulfillment of the requirements for the degree of Master of Science.

1958

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ACKNOWLEDGEMENTS

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The author wishes to express his sincere appreciation and admiration for Dr. E. G. Muirhead's untiring efforts to obtain the data reported. His ever ready assistance and numerous nights spent in the laboratory to get running time on the betatron and analyzing data were a major contribution to this paper.

Thanks are also due to K. Geller, who suggested this project and in whose work the results will be used, to the E. I. du Pont de Nemours Company of Wilmington, Delaware, for providing the silicon samples, to T. Coyle and the men in the machine shop for their interest and prompt accomplishment of the necessary work, to L. Chihas, laboratory technician, and to Miss M. Kreiter, who typed the preliminary drafts of this paper.

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INTRODUCTION

This paper will describe the work done in the Betatron Laboratory toward determining the thresholds for the (γ, n) reactions of several light elements; in particular, magnesium, aluminum, and silicon, by measuring the residual activity of the short half-lived products of the reactions. This involved measuring the positron activity of products with half-lives of the order of 2 to 12 seconds. The immediate results of this project, and those reported in this paper, were the determination of the half-lives of the activities under consideration. The final threshold work will be done by another student as part of his dissertation. This work was undertaken as an aid to his work.

The paper has been divided into the following sections: theory, problem, equipment, operation, and results.

THEORY

The reactions of nuclei with electromagnetic radiation is a lucrative source of information about the nucleus. These reactions, known as photonuclear reactions, can be used to study the level structure and binding energy of the outer particles of the nucleus. The (γ, n) reactions, those in which a neutron is released, were the ones of primary interest in this instance.

It was desired to measure the thresholds for the (γ, n) reactions for the three light elements: magnesium, aluminum, and silicon. To do this, the reaction is produced by irradiating targets of the material under study with x-rays produced by a betatron. The reactions can then be observed in either or two ways. The neutrons produced in the reactions can be observed as they leave the target, or the residual activity of the product of the reaction can be observed. In the experiment under consideration, the second method was chosen.

In observing the (γ, n) reaction by this method, the target is irradiated with x-rays of various energies and the resulting activity is measured for each energy. When activity is plotted against the energy, an activity curve is obtained. The location of the initial rise in activity in this curve gives the threshold energy for the reaction.

However, there are other things to consider. The x-rays used are produced by a betatron, in this case an Allis-Chalmers machine of maximum energy of 25 Mev. The x-rays produced are

the bremsstrahlung from accelerated electrons impinging upon a platinum target. This produces a continuous spectrum of energies with a well defined maximum. The intensity distribution of this spectrum is important when it is desired to reduce the activity data taken to a cross section curve for the reaction. For measuring the threshold energies, the activity curves are plotted as functions of the maximum bremsstrahlung energy.

Considering a pure target, there will be only one activity present to be counted. And if only the activity of the target is counted, the activity observed will be due only to a reaction in the target. But there may still be activity due to two different reactions such as (γ, n) and a (γ, p) reaction. Thus it is necessary to separate the activity desired from that of extraneous reactions, impurities, associated materials, and background. To do this, the origin of the interfering activities must be determined so that they can be eliminated if they obscure the desired threshold, or taken into account as corrections if they cannot be removed.

The origin of the activity observed is determined by measuring its half-life. Then by comparing it to the half-lives in a table of isotopes, the source of the activity can usually be identified.

The characteristics of the three elements under consideration pose some problems when one tries to measure the thresholds by activity. The general characteristics are as shown in Table I.

TABLE I

Isotope	% Abundance[1]	Reaction	Calculated[2] Particle Binding Energy, Mev	Product	Half-lives[3] of Product
Mg^{24}	78.6	(γ,n)	14.282	Mg^{23}	10.7-12.3 s.
Mg^{25}	10.1	(γ,p)	12.100	Na^{24}	14.97-15.10 h.
Mg^{24}	11.3	(γ,p)	13.684	Na^{25}	60 s. average
Al^{27}	100	(γ,n)	13.675	Al^{26}	6.3-7.2 s.
Si^{28}	92.28	(γ,n)	15.169	Si^{27}	4.1-4.9 s.
Si^{29}	4.67	(γ,p)	12.223	Al^{28}	2.07-2.31 m.
Si^{30}	3.05	(γ,p)	13.622	Al^{29}	6.56-6.7 m.

The problem of the short half-lives must be taken care of by arranging a method for eliminating the time lapse between irradiation and counting, and in order to obtain sufficient counts to give acceptable statistics to the results, the best counting efficiency possible must be obtained.

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(1) Handbook of Chemistry and Physics, Chemical Publishing Company (1957)

(2) A. G. W. Cameron, Report CRP-690 (AECL-433)

(3) D. Strominger, et al, Rev. Mod. Phys. 30, 2, pt. II (1958)

There are several ways in which the counting could be done. The positrons could be counted directly, or the annihilation radiation of the positrons could be counted. In this case, it was decided to count the positrons directly. Since the counter would be in the same room as the betatron, a scintillating material which was relatively insensitive to gamma radiation and neutrons, but quite efficient for charged particles, was desirable. This would allow good counting of the positrons while reducing the effects of background gamma radiation and activities resulting from (n,γ) reactions produced by the neutron flux in the betatron room.

Since the activity to be counted was expected to be low in the vicinity of the thresholds, it was desirable to keep the counting efficiency as high as possible, and to obtain as many positrons from the target as possible. In order to obtain the first of these conditions, it was desirable to have as nearly 4π geometry for the counting process as possible. If the target were entirely within the scintillating material during counting, the best efficiency would be obtained. For these reasons, a liquid scintillator was chosen. Using a liquid would allow complete immersion of the target for counting and, if the volume of scintillator were large enough, all the positrons would be counted except those absorbed in the target itself. In order to reduce the absorption of the target, it was desirable to make the target as thin as practical. However,

to get as much activity as possible, it was also necessary to have as much material in the target as possible. In order to meet these conflicting requirements, it was decided to make the target an array of strips and arrange them so that the PM tube looked at it along the direction of the long dimension of the strips. To decide upon the dimensions and arrangement of the target strips, the following calculations were used as a guide.

Half intensity angle of the betatron beam: $\frac{1}{2}\measuredangle \approx 6^\circ$ at 22 Mev

Target distance from betatron target: $d \approx 24''$

Width of betatron beam of half intensity at target: $W \approx \frac{6}{57.3} \times 24 = 2.5''$

The target arrays were made with a width of $1\frac{1}{4}$" to keep them well within the section of the beam of higher than half maximum intensity.

Next, using a curve of beta energy in Mev versus range in milligrams per square centimeter for the absorption of beta particles in aluminum,(4) the range of the positrons was calculated in each of the target materials and in toluene (the solvent of the scintillator).

Target	Positron(5) Energy Mev	Target(5) Density g/cc	Range in Aluminum g/cm^2	Calculated Range in Target cm	Calculated Range in Toluene cm
Toluene		0.866			
Mg^{23}	2.99	1.74	1.5	0.86	1.73
Al^{25}	3.24	2.70	1.7	0.63	2.0
Si^{27}	3.76	2.40	1.9	0.79	2.2

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(4) American Institute of Physics Handbook

(5) Handbook of Chemistry and Physics, Chemical Pub. Co. (1957)

Calculation for aluminum:

$$R_T = \frac{1.5}{.866} = 1.73 \text{ cm}$$

$$R_{al} = \frac{1.5}{1.74} = 0.86 \text{ cm} \qquad \times \frac{1}{10} = .86 \text{ mm}$$

The ranges calculated above are the practical ranges. one tenth of the calculated range value will give a thickness which will allow approximately 80% of the particles to escape. Thus, by making the target strips 1/8" x ½" (.32 cm x 1.15 cm) in cross section, nearly all of the positrons produced in the strips will get out into the scintillator. Then, if the strips are spaced at least ¼" apart, the positrons will stop in the scintillator. This still leaves the problem of beam absorption if several of the strips are placed in line with each other. The mass absorption coefficients(6) were taken from NBS report 1003 (1952) for 15 Mev and are as follows:

Aluminum	0.0219	cm^2/gm
Silicon	0.0234	cm^2/gm
Air	0.0180	cm^2/gm

Then the calculation for aluminum and for the air over the length of the target is as follows: $\mu = \mu_\rho / \rho$

For al: $$\frac{I}{I_0} = e^{-\mu x} = e^{-.219 \times 1.74 \times \frac{2.54}{8}}$$

$$= .988 \text{ for } \tfrac{1}{8}" \text{ of al}$$

$$= .976 \text{ for } \tfrac{1}{4}" \text{ of al} = .964 \text{ for } \tfrac{3}{8}" \text{ of al}$$

For air: $$\frac{I}{I_0} = e^{-\mu x} = e^{-.018 \times .001185 \times 2.54 \times 4}$$

$$\simeq 1 > .999 \text{ for } 4" \text{ of air}$$

---

(6) G. R. White, National Bureau of Standards Report 1003.

The next consideration was the time of irradiation. Using $N = Kt(1 - e^{-\frac{691t}{\tau}}$ where N equals number of nucleii, K equals a constant, t equals time, and τ equals the half-life, the following irradiation times were obtained:

Irradiation Time in Half-lives	Percent Saturation	Counting Time in Half-lives	Percent Residual Activity
3	87.5	3	12.5
5	97	5	3.0
7.5	100	6	1.6

This information shows that for the best results, the target should be irradiated at least 5 half-lives in order to get the maximum activity without wasting time. It also shows that after counting for five half-lives, the activity will have fallen essentially to background. Essentially, this means that the counting cycle will have to extend to at least five half-lives for best results. The irradiation time can be varied to keep the initial activity within usable limits, or to keep undesirable long lived activity to a minimum.

THE PROBLEM

The problem at hand was to construct a device to use in measuring the (γ,n) thresholds for several light elements by measuring the residual activity of their short half-life products. This involves measuring the activity of isotopes with half-lives of the order of 2 to 12 seconds.

The problem could be divided into several parts. The primary part was to construct a mechanism which would hold the target in the x-ray beam in a fixed and reproducible position for a controllable length of time and then remove the target rapidly to the counter. It must then hold the target in the counter in a fixed and reproducible position for a controllable length of time.

With the short times involved, it was also desirable that the device control the starting and stopping of the irradiation and counting process. And in order to improve the statistics of the data obtained, it was desired that the mechanism operate on a continually repeating reproducible cycle to make best use of the available time on the betatron.

Then, the counting process involved would entail counting a relatively low activity with a high initial counting rate due to its short half-life.

EQUIPMENT

The device constructed to solve the problem as described above is shown in Figure 1, and its various components are shown in Figures 2, 4, and 6. The device was designed to position the target samples and control the operation of the betatron and counting equipment in order to irradiate the sample and then count the residual activity.

The device can be separated into three basic components which are mounted on the stand and chassis racks as appropriate.

The first basic portion is the positioning mechanism. The problem here was one of holding the target in the x-ray beam, then moving it down into the scintillating material in order to count the activity, and then moving it back into the beam. This had to be accomplished rapidly with control of the downward movement and the operation had to be positive and reliable. This was accomplished by using a double acting air cylinder mounted vertically with the target attached directly to the piston rod. The movement of the piston was adjusted to adjust the position of the sample.

The cylinder used was a Modernaire, 1-1/8" diameter double acting air cylinder. This size piston provided a force equal to the air pressure applied when the exhaust for the opposite end of the cylinder is not restricted. Thus considering a target and piston assemblage weighing approximately one pound and

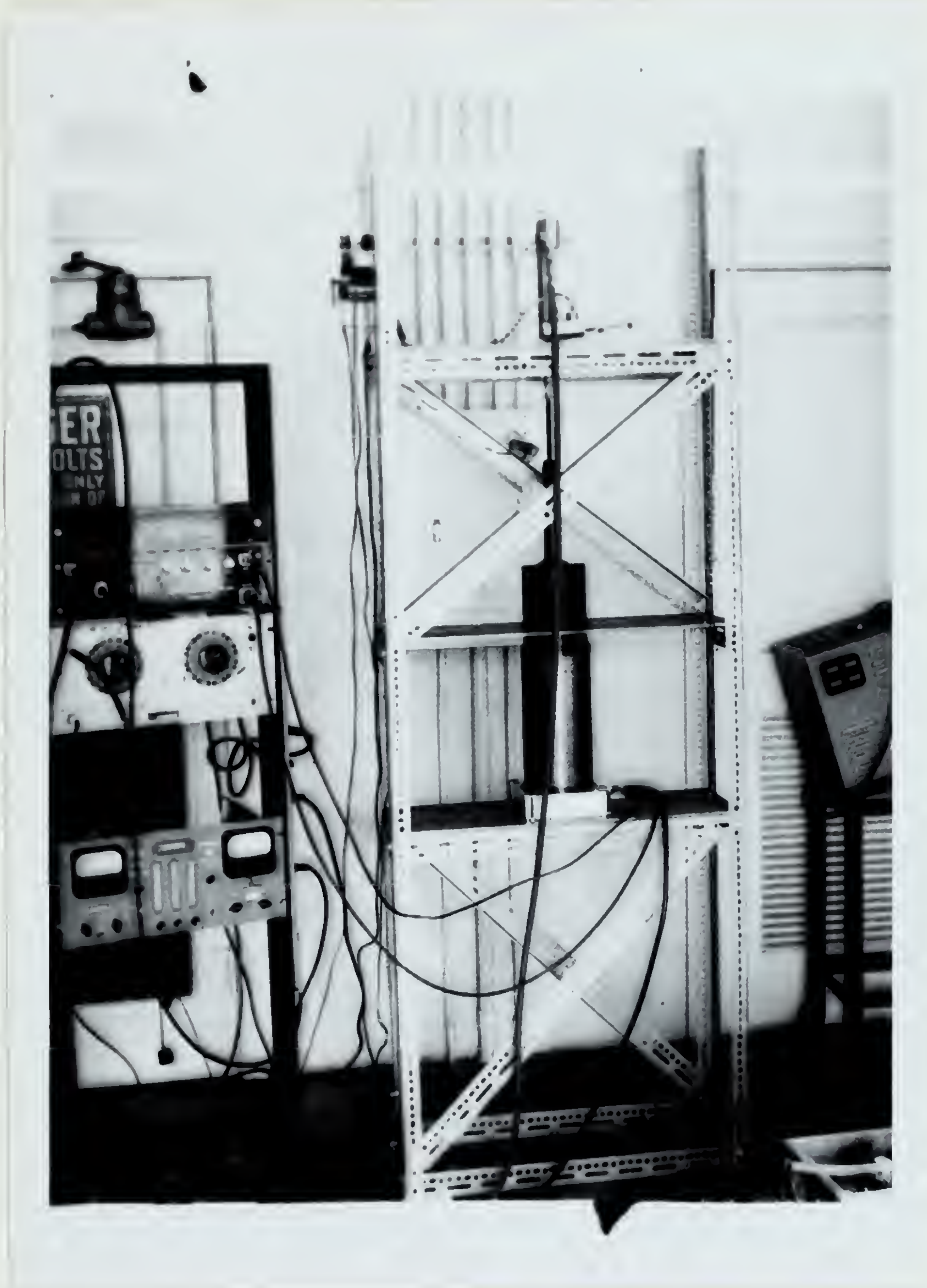


Figure 1. Overall view of device and associated electronics.

an applied air pressure of 50 pounds. A minimum time of travel can be found for a piston travel of 6".

$$F = ma \qquad s = \frac{1}{2}at^2$$

$$t = \sqrt{\frac{2sm}{F}} = \sqrt{\frac{2 \times \frac{1}{2} \times 1}{50 \times 32.2}}$$

$$= .079 \text{ sec}$$

This time was more than sufficient considering the half-lives involved. In fact, considerations such as delays required to cause proper operation of the counting equipment and the problem of splashing in the liquid scintillator used dictated a much slower rate of fall than that which was at first anticipated. The positive action of this mechanism also precluded any bounce or oscillation at the end of the stroke. In order to control the downward rate of travel, a needle valve, as shown in Figure 2, was attached to the exhaust side of the valve at the bottom of the cylinder. It was thus possible to control the rate of fall from almost the maximum to a minimum of the order of seconds. This controlled time of fall allowed the introduction of the required delays mentioned above. The cylinder was operated with solenoid controlled valves which provided for the required remote and automatic operation. The air supply used was the laboratory supply which was reduced from 50 to 15 p.s.i. gauge and the cylinder was exhausted to the atmosphere. The rate of fall had to be set manually. The stroke of the piston was adjusted by means of lucite sleeves slipped over the

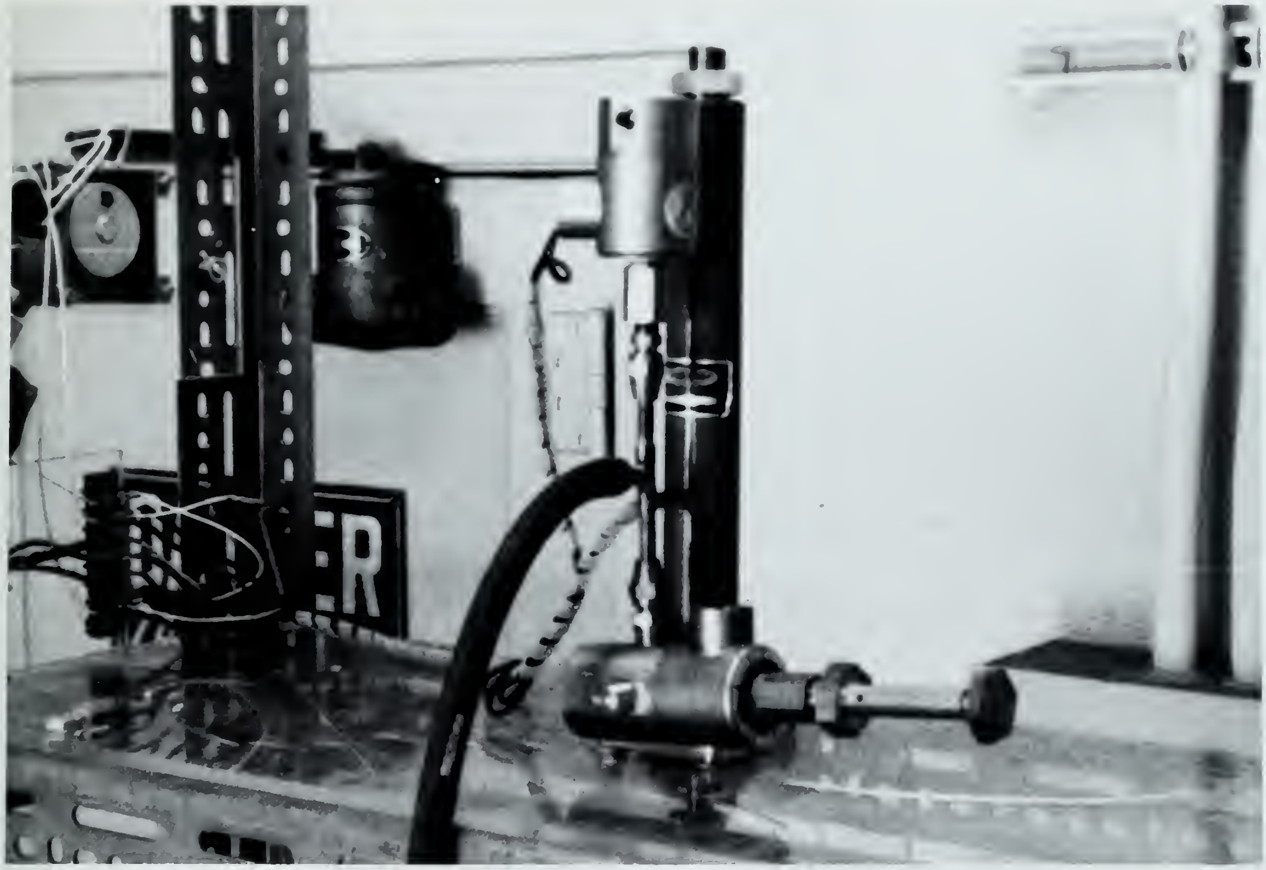


Figure 2. Air cylinder, solenoid valves, and needle valve assembly.

piston rod. The cylinder used had a stroke of eight inches. The bottom position was fixed, but the lowered position of the target could be adjusted by approximately ½" with the connecting sleeve, which connected the piston rod to the extension on which the target was mounted. This can readily be seen in Figure 4. The lucite sleeves could then be used to adjust the top position through the full eight inches of travel by adjusting the stroke allowed.

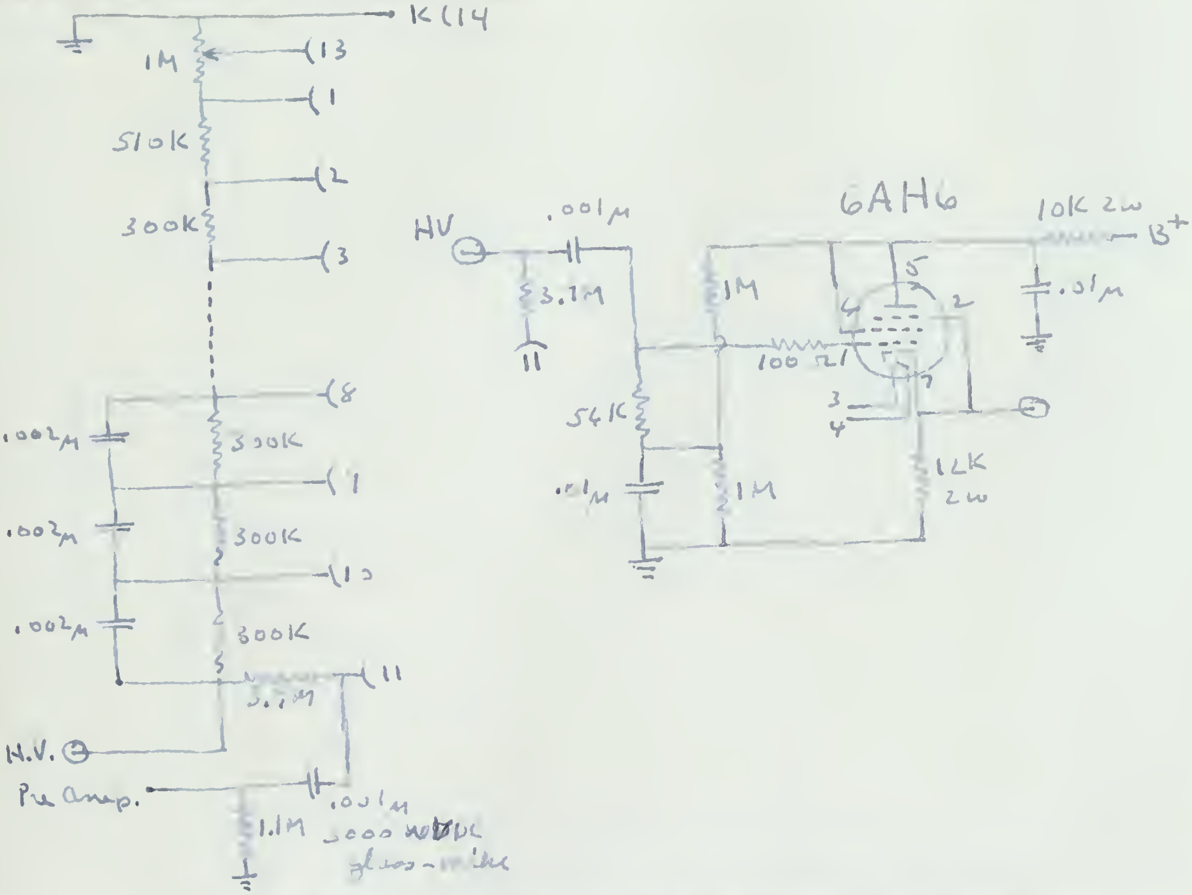


Figure 3. Preamplifier and voltage divider.

The next component of the device is the counter. This was a scintillation counter using a 5" Dumont 6364 photomultiplier

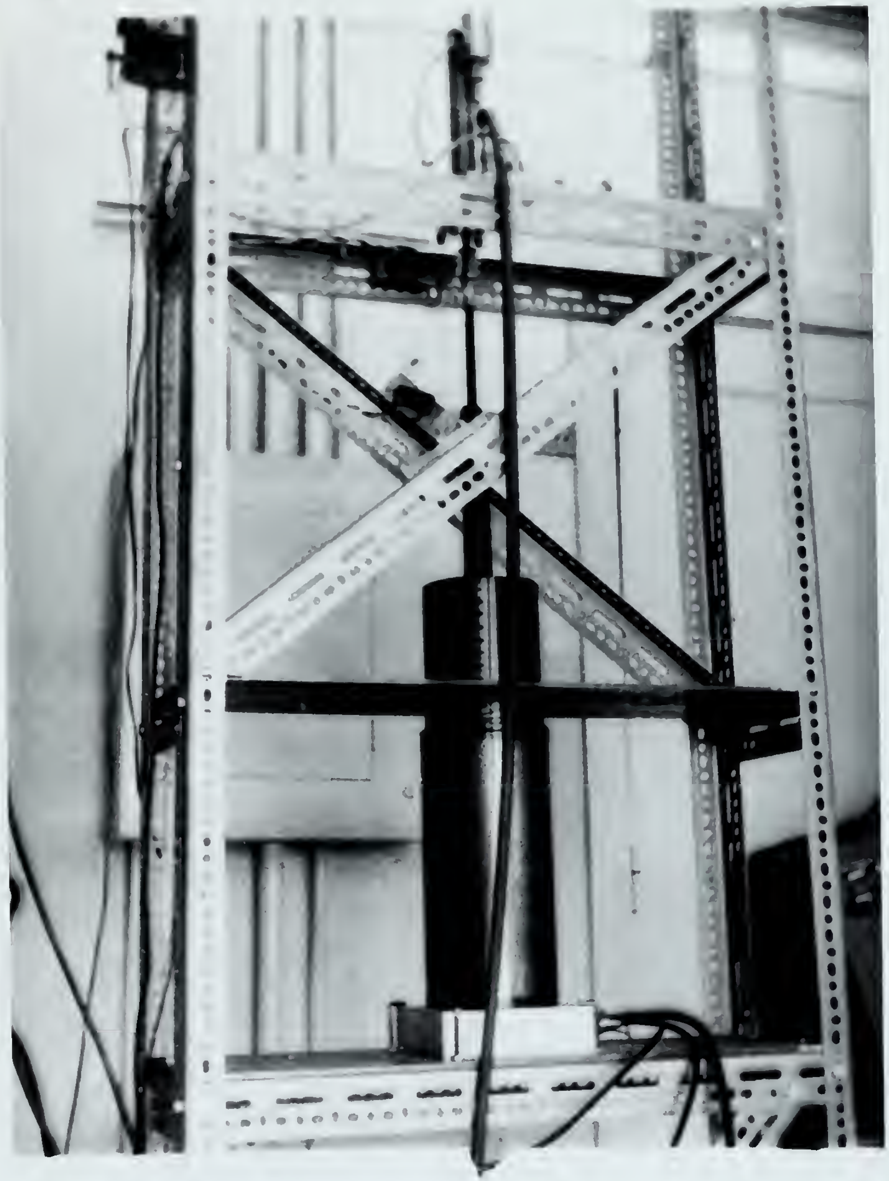


Figure 4. View of counter and air cylinder assemblies showing control microswitches.

tube and a liquid scintillator. The scintillator used was manufactured by the Isomet Corporation. It is a solution of p-triphenyl in toluene with a trace of diphenylhexatriene as a wave length shifter. The PM tube was mounted on a chassis containing the preamplifier and voltage divider as shown in Figure 3. The electronics used were a Cosmic model 101 amplifier, Atomic model 510 single channel analyzer, Atomic series 1010 scaler, and a Fluke model 400F high voltage power supply. The preamplifier used is shown in Figure 3. It is a low input impedance type which was used to reduce the effects of pickup. It was supplied with a negative high voltage and 300 volt B^+ supply.

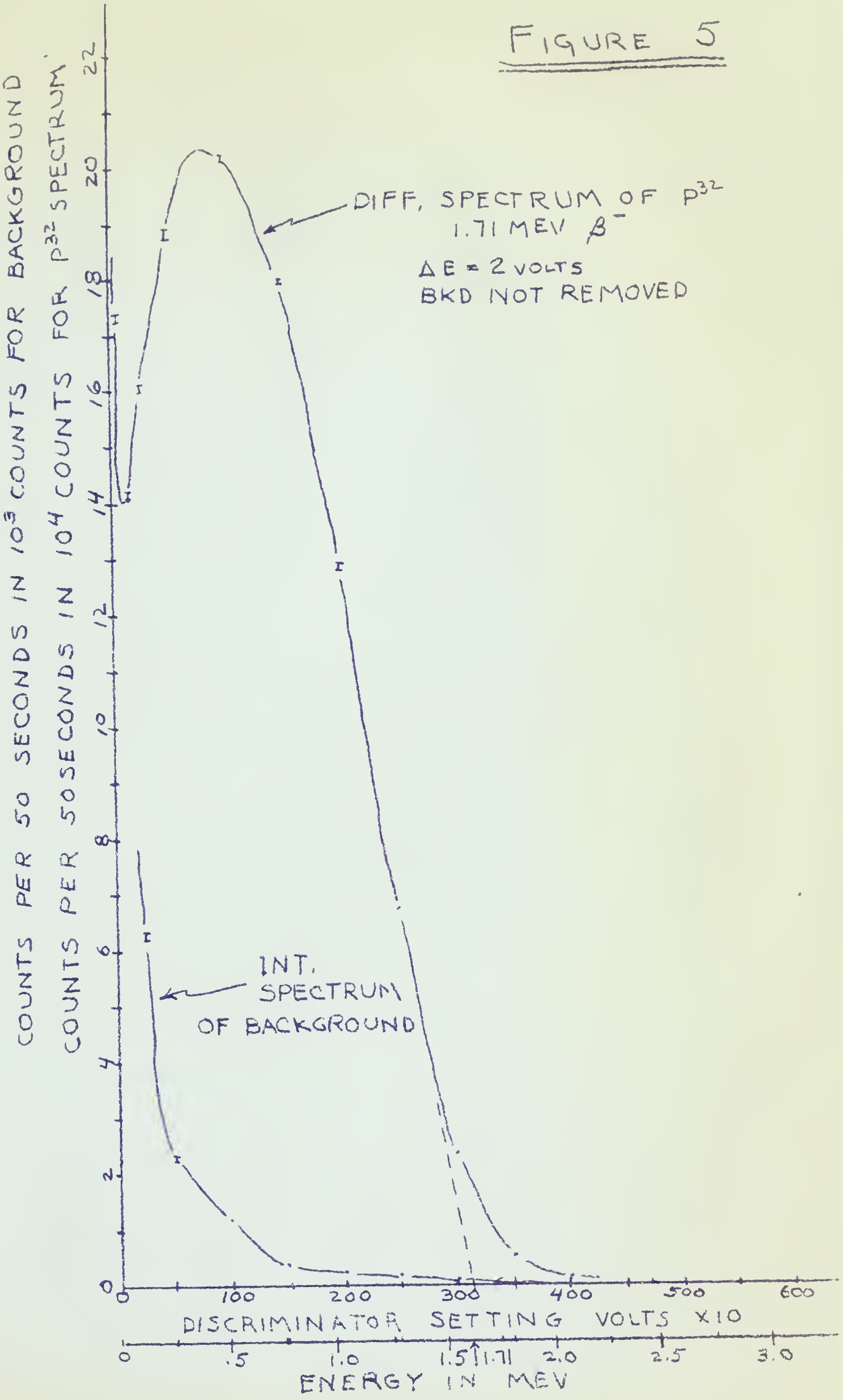
The outside cylinder of the PM assembly was made of steel tubing. This was used in order to provide magnetic shielding for the PM tube, and because the extraneous activity induced in it by the neutron flux and stray x-rays in the machine room could be expected to be low enough in intensity and of such a half-life as not to interfere with the activity that was to be counted. The steel tube was divided approximately 1/3 of its length from the top by a lucite plate to form a tank for the liquid scintillator in the top third. The face of the PM tube was optically joined to this plate with high viscosity silicon oil. The lucite plate was machined for a press fit into the tube and was forced into place, then the tube and plate were drilled to accept small machine screws. This operation made a liquid tight seal and no other sealant was required; but, for

safety, Duco Cement was used as an additional seal. The tank portion of the tube was then lined with stainless steel sheet in order to prevent rust and provide a reflecting surface. This sheet was cut and rolled for a press fit into the tube. This arrangement was satisfactory and provided plenty of room for the targets used. However, the space required for target insertion was much less than the size of the tank. So a lucite insert was put into the tank to reduce its size. The insert was also lined with stainless steel sheet to provide a reflecting surface. This insert, as shown in Figure 6, reduced the size of the tank to 2 x 4 x 4¼". This was large enough for the targets used and reduced considerably the amount of scintillator required. Reducing the amount of scintillator also reduced the background without affecting the counting of short range charged particles. Figure 5 shows a background curve and an energy calibration curve taken, using P^{32} as a source, for the final configuration of the tank.

The top of the tank was left open. The plate in which the target was mounted was used as the top of the tank. This did not completely cover the tank but did provide a satisfactory cover.

Next, a cover for the tank which would allow room for the movement of the target and through which the target would be irradiated was required. This was made from lucite tubing as shown in Figure 6. This tubing was 5" o.d. and just slipped

FIGURE 5


COUNTS PER 50 SECONDS IN 10^3 COUNTS FOR BACKGROUND
COUNTS PER 50 SECONDS IN 10^4 COUNTS FOR P^{32} SPECTRUM
0
2
4
6
8
10
12
14
16
18
20
22
DIFF. SPECTRUM OF P^{32}
1.71 MEV β^-
$\Delta E = 2$ VOLTS
BKD NOT REMOVED
INT. SPECTRUM OF BACKGROUND
0
100
200
300
400
500
600
DISCRIMINATOR SETTING VOLTS X10
0
.5
1.0
1.5
1.71
2.0
2.5
3.0
ENERGY IN MEV

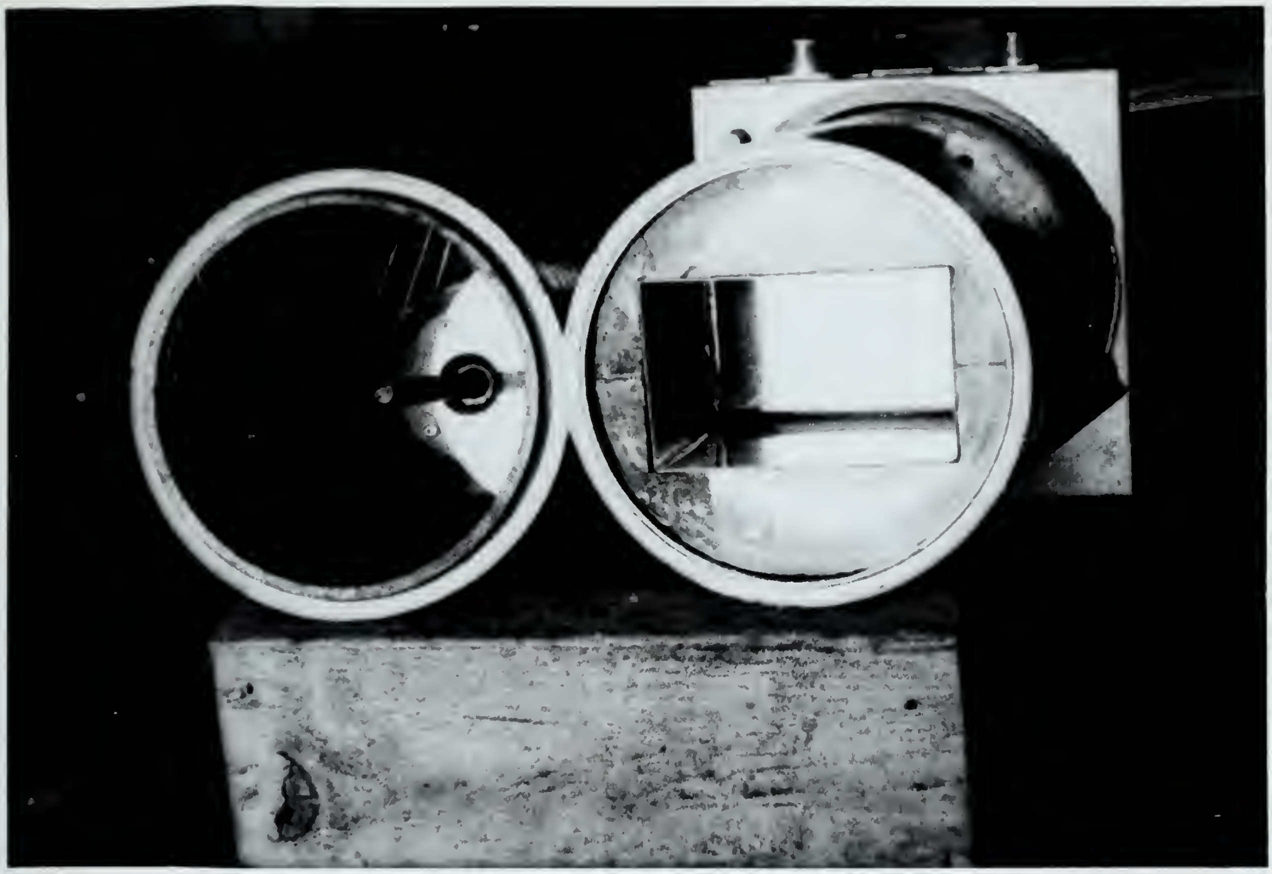


Figure 6. View of interior or scintillator tank and plastic cover of the counter.

into the steel tubing. A flange was added to hold it in position and a strip of Scotch brand electrical tape was used to seal this joint in the final assembly. This was surmounted by a smaller diameter tube 8" long, with a guide for the piston rod extension at each end. This provided guidance for the travel of the target and eliminated whip in the long piston rod.

For light tightness, the whole cover was taped with Scotch brand electrical tape and a piece of heavy black cloth was used around the hole through which the rod moved. The piston rod was made of opaque plastic because it was found that lucite made a very effective light pipe and it was impossible to make the whole assembly light tight using a lucite rod. Windows were cut in the wrapping and covers of black paper were taped over them. The windows were necessary in order to observe the adjustment of the target position. They were also used to check for any splashing that might occur, so that it could be eliminated.

Attached to the bottom of the plastic cover was a fitting to allow the introduction of an inert atmosphere over the scintillator. This was done to reduce the oxygen absorption and to remove oxygen and nitrogen from within the counter. The gas used was argon, and it was fed into the fitting at the base of the cover from a cylinder and allowed to flow out through the clearance around the piston rod extension. A rate of flow of about two cubic feet per minute was sufficient.

The next portion of the device to be considered is the control mechanism. The primary control was an Industrial Timer

Corporation CM-2 cam timer, as shown in Figure 7. This is essentially a timed cycle of opening and closing a microswitch. This microswitch controlled the solenoid valves. Another microswitch, also shown in Figure 7, was added to operate from the same cam and controlled the cutoff of the scaler. This will be discussed more fully under the operating cycle of the device. The rest of the controls consisted of two microswitches mounted on the stand, as shown in Figure 4, and operated by an arm attached to the piston rod. One switch was mounted at each end of the stroke. These controlled the betatron injection and the scaler starting.

The targets used were made of aluminum, magnesium, and silicon. The aluminum and magnesium samples were spectroscopically pure and the silicon used was cut from single crystals. From considerations previously mentioned in the first section of this paper, the targets were constructed of strips of material ½" x 1/8" x 3½", fastened in a lucite plate to form a geometrical array, as shown in Figure 8. The lucite plate was made 1½" x 3½" x 3/8". The strips were attached to this plate by pressing the ends of the strip into slots machined to exactly fit the ends of the strips. This method precluded the necessity of using any type of glue or other fastening devices to hold the strips to the plate. The size of the targets was such that they could be completely immersed in the scintillator with the plate surface in contact with the surface of the

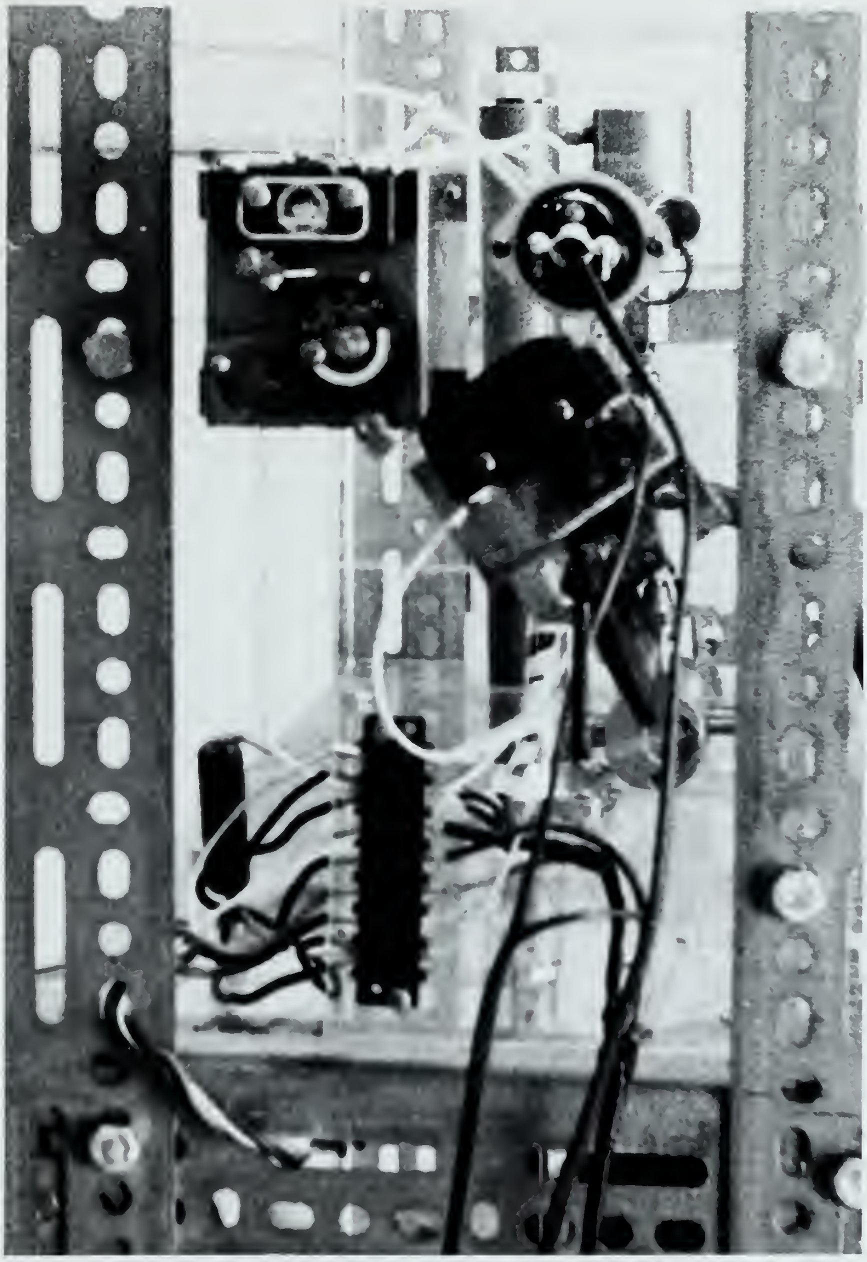


Figure 7. Cam timer and microswitches for controlling air valves and scaler cutoff.

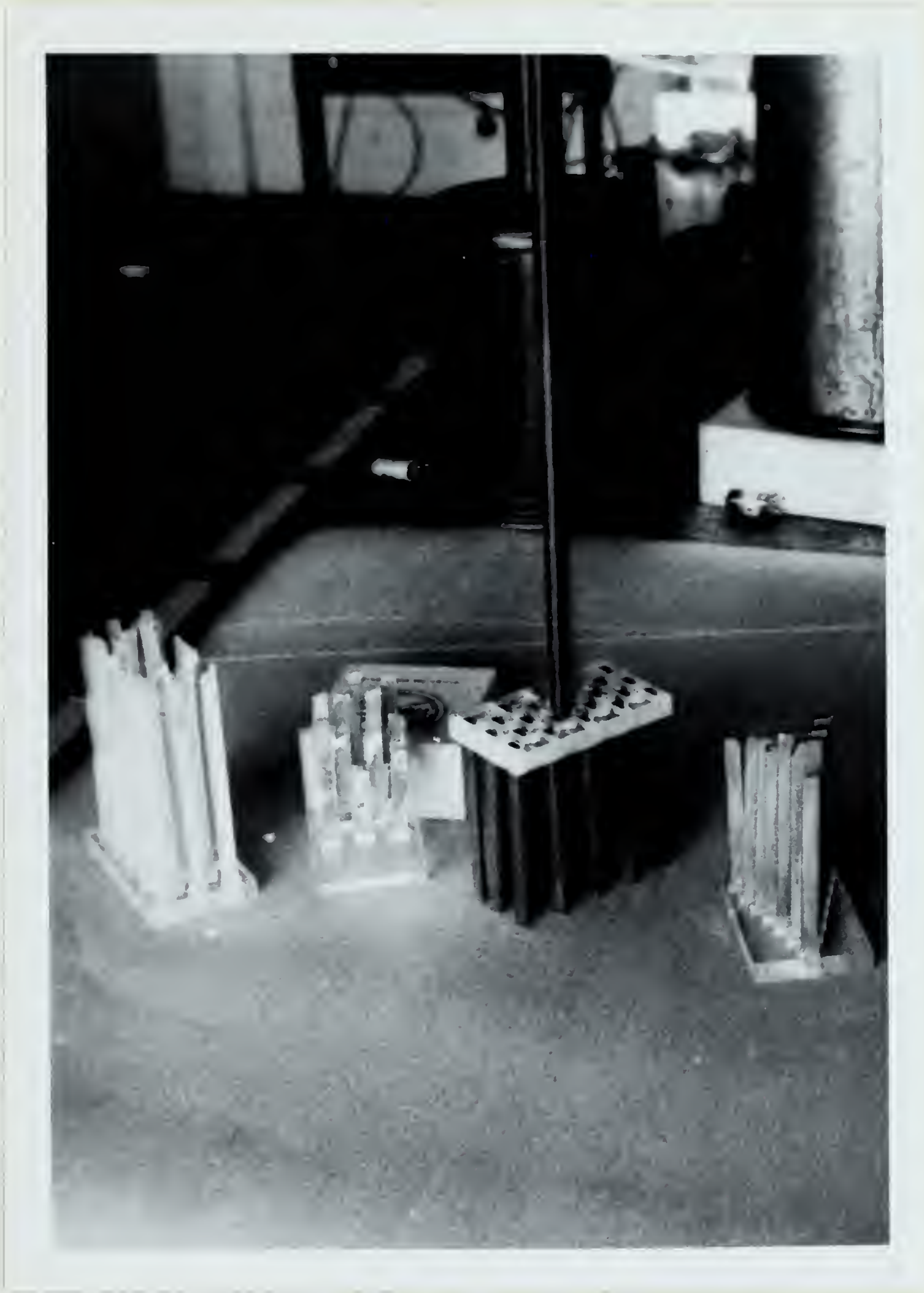


Figure 8. Targets

scintillator.

The data was taken from the scaler with a Brush model BL-201 single pen recorder. The cascade output from the scaler was fed into the amplifier of the Brush recorder and the data recorded on the tape. The recorder was connected to the remote control of the scaler so that it was started and stopped remotely with the scaler. Taking the data in this manner gave a permanent record of the variation of the activity with time. The total activity and the half-life could both be obtained from these tapes. A cursory visual check of the tapes also served as an approximate check on the threshold of the activity being recorded.

OPERATION

The device was designed to perform a cycle automatically so that a sample of short half-life could be alternately irradiated and have the activity induced counted without loss of time. The cycle of operation, starting in the irradiation condition, was as follows: activate air valves to move sample down; movement breaks betatron injection circuit; delay in fall; end of travel, scaler starts; activate air valves to lift sample; movement stops scaler; end of travel, close betatron injector circuit. When this cycle was tried, it was found that pickup from the activation of the air valves was a problem. This was eliminated by putting in a second microswitch, shown in Figure 7, operating on the cam timer, which would stop the scaler before the air valves were activated.

The operation of the betatron was controlled by a microswitch, breaking the injector circuit in the a.c. side just before the variac for controlling the injection voltage.

The shielding used was as follows: A 6" thick lead wall with a 1" diameter collimator located just behind the betatron; a 2" lead wall just in front of the counter assembly, on the steel plate on which the counter was mounted and built up to the steel plate just below the beam; a 1" layer of lead on the steel plate just below the beam; and a 2" lead wall on either side of the upper portion of the counter.

Overall, the prospects of measuring thresholds with this device appear to be good. The background can still be reduced, and the activities observed should be quite adequate even near threshold.

RESULTS

The data taken thus far is actually of an exploratory nature. Due to limitations of time, it has not been possible to obtain the extensive data which would be required for the maximum accuracy possible with the equipment at hand. The same limitations of time have made it impossible to give the existing data the extensive study it needs. However, within these limitations, the data taken has produced satisfactory results.

Runs were made at various energies from slightly above threshold to well above threshold in order to determine the best conditions under which to run. The first portion of each tape was one cycle of background and the counting after irradiation was carried out until the appearance of the tape indicated that background had again been reached. This gave a counting time of at least five half-lives for the longest lived activity expected. The raw data was in the form of recorder tapes which had to be read, counting the activity and tabulating the results.

The data was reduced to usable form in the following manner. The tape speed was known and the tape was marked off in one second intervals as it was read. The speed was calibrated on each run by a 60 cycle signal recorded on the tape. The activity count was tabulated for each one second interval to the nearest 10 or 100 counts, since the tape only recorded

every 10th or 100th count, depending upon the input selected. This raw data was then plotted and the curve smoothed on the second trial by averaging over intervals of three seconds, as appropriate for the particular curve. The cold background was then subtracted and the curve checked for any long lived activity. If such activity was found, it was identified and subtracted out to leave the curve for the short half-life activity which was of interest. The best visual fit was then made to the curve for a determination of the half-life. The maximum error was then obtained by fitting extreme curves to the data.

One tape for each of the elements was analyzed and the results are as follows:

SILICON

Tape XXIX   Energy 18.5 Mev   Tape speed 12.5 cm/sec
Count by 10's   15 sec. irradiation
Initial background   60.4 ± 2.8/sec
Results plotted in Figures 9 and 10
Half-life: 4.47 ± .32 sec.

ALUMINUM

Tape XXIII   Energy 17 Mev   Tape speed 12.5 cm/sec
Count by 10's   15 sec. irradiation
Initial background   116 ± 15/sec
Results plotted in Figure 11
Half-life: 7.12 ± .78 sec

MAGNESIUM

Tape XXXII Energy 19 Mev Tape speed 12.5 cm/sec

Count by 100's changing to 10's after approximately 60 sec

45 sec irradiation

Initial background 70 ± 13/sec

Results plotted in Figure 12

Half-life: Mg^{23} - 11.11 ± .11 sec

Na^{25} - 56.5 ± 1.7 sec

The results obtained from the silicon give a half-life of 4.47 sec for Si^{27} with good accuracy and in good agreement with the quoted values in the literature. The long lived activity was unexpected. There are two possible sources. First, it could be Al^{29} resulting from the (γ,p) reaction with Si^{30}. The quoted half-life is 6.56 - 6.7 minutes. The value of 6.47 minutes obtained is within agreement with this, but if it is from Al^{29}, one would think that the activity from the (γ,p) reaction with Si^{29} to produce Al^{28} would appear also since the abundance of the two isotopes is nearly equal and the energy used in irradiation was well above both thresholds. Since both of these activities are not present, it seems unlikely that this is the source. The other possibility is Br^{78}. This is possible because there is a small amount of bromine in the silicon used but the quoted impurities of several parts per million would have to be in error to give the activity obtained. However, this possibility is believed to be the most likely one.

The results obtained from the aluminum give a half-life of 7.12 sec for Al^{26} with good accuracy. No other appreciable activity was found. There was an indication of a small amount of a much longer lived activity which was assumed to be due to neutron absorption and to have a half-life of the order of 10 minutes. An activity of about five percent of background was subtracted for this and resulted in smoothing the curve of the primary activity.

The results obtained for the magnesium give a half-life of 11.11 sec for Mg^{23} with very good accuracy and a half-life of 56.5 sec for Na^{25} with good accuracy. It was not expected that the activity from Na^{24} would show up because the half-life is nearly three orders of magnitude longer than Na^{25}.

The results as a whole are very good. The results from the magnesium are the best obtained. This is the result of applying the experience gained from the runs made on silicon and aluminum. It should not be difficult to obtain the desired half-lives to an accuracy of about one half of one percent by making at least five runs on each element, counting the longer half-lives by units instead of tens, using higher energies, and keeping a better and continuous check on the background independently of the tapes.

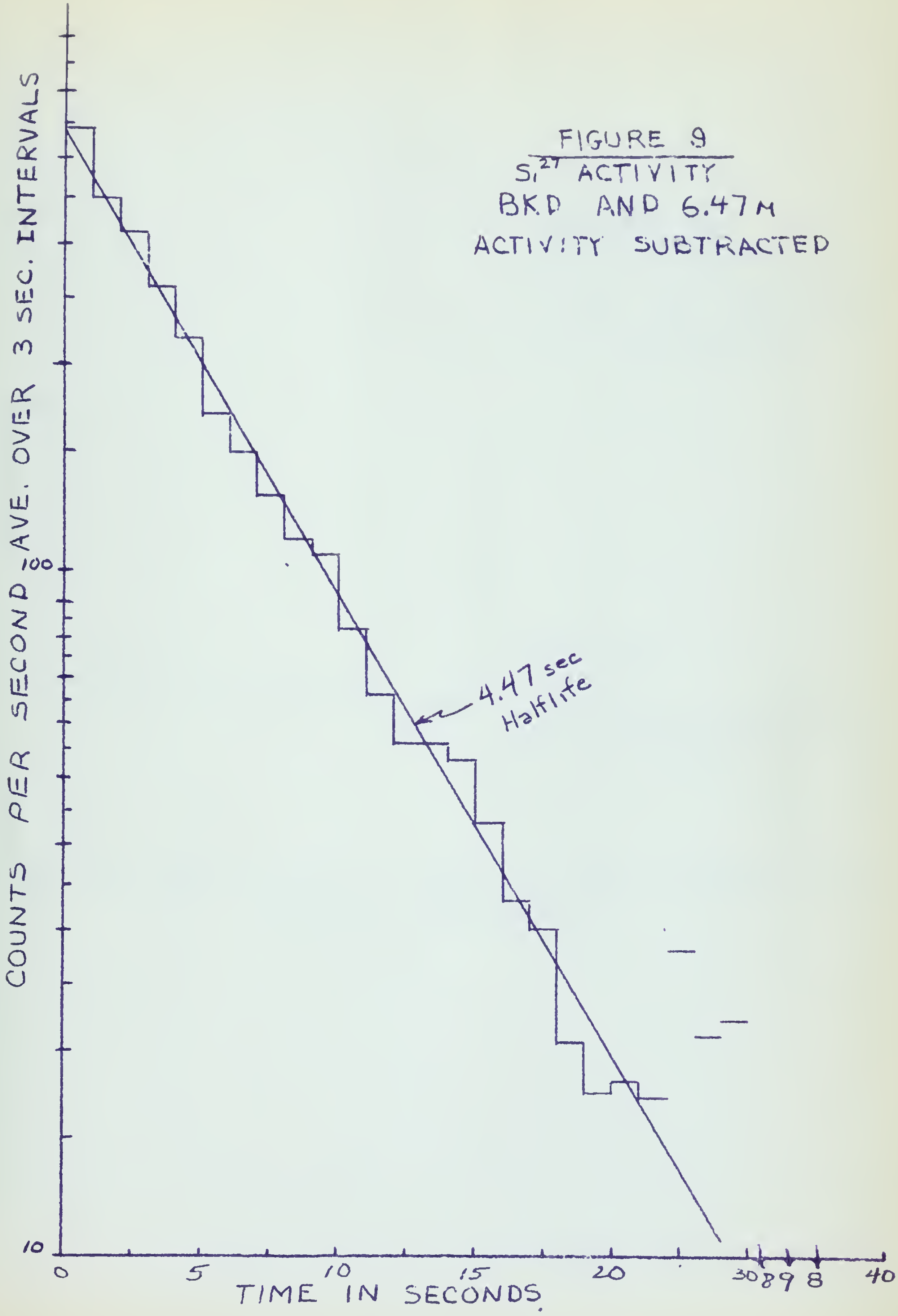


FIGURE 9

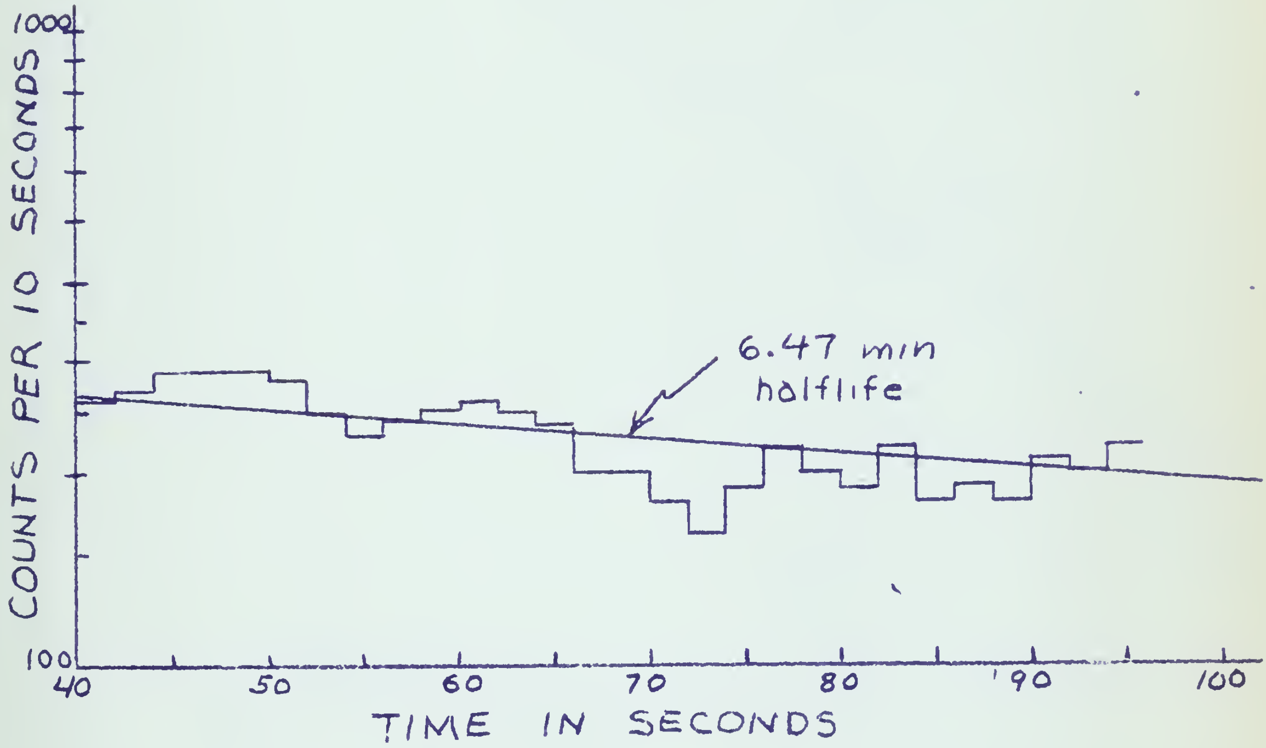
Si^{27} ACTIVITY

BKD AND 6.47M

ACTIVITY SUBTRACTED

FIGURE 10

SILICON ACTIVITY
AFTER 40 SECONDS
BKD SUBTRACTED



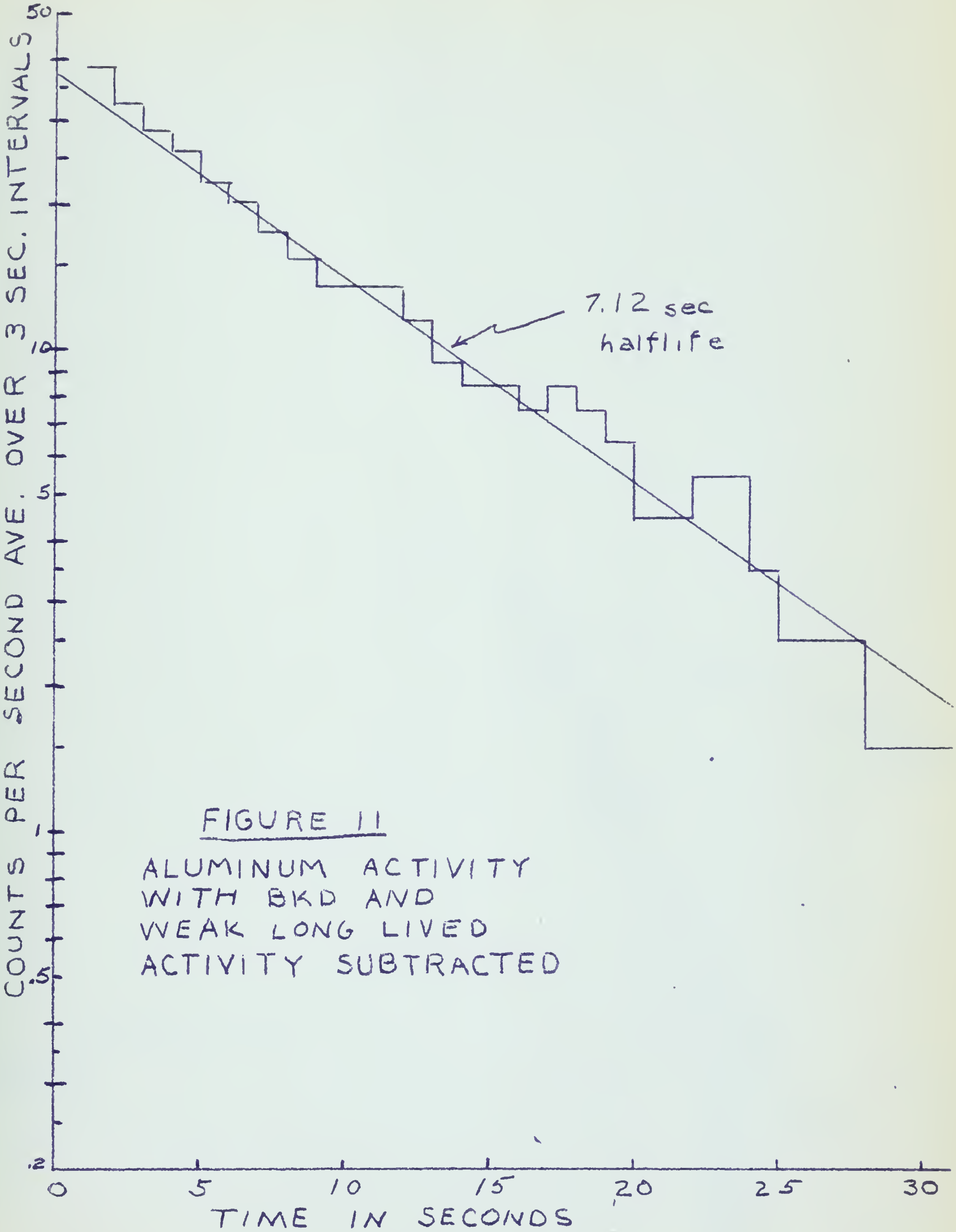
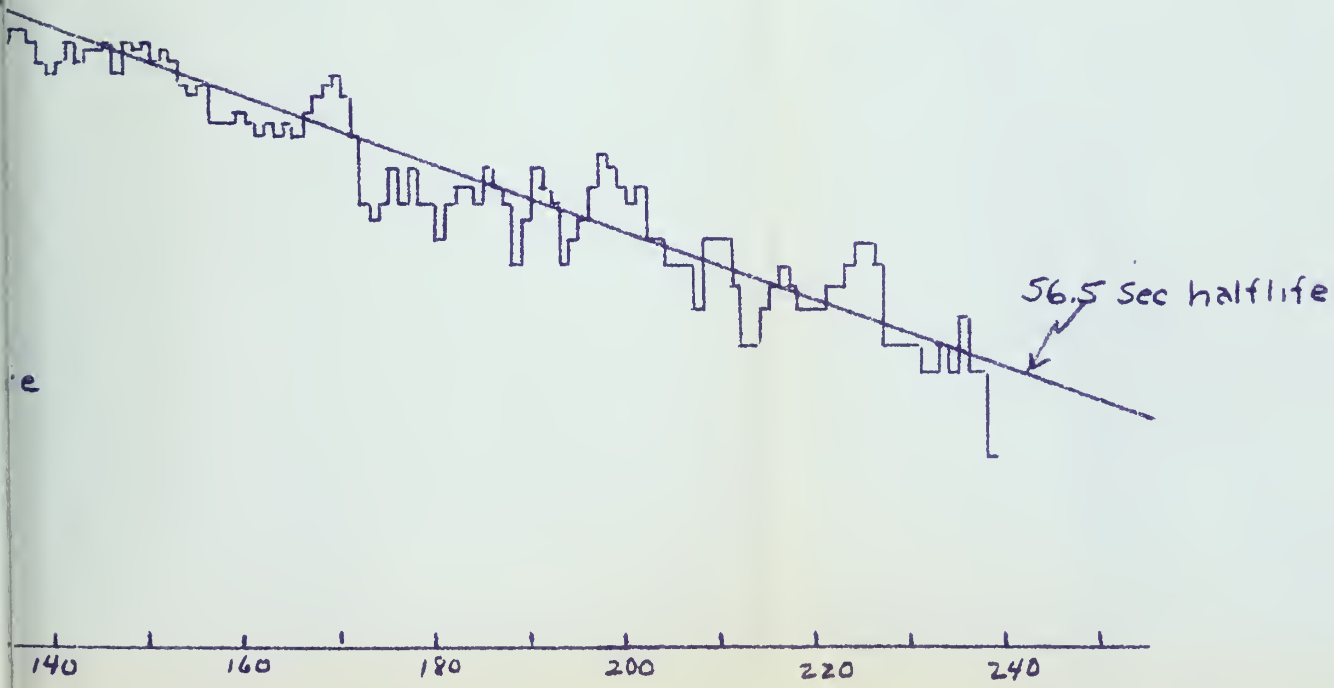
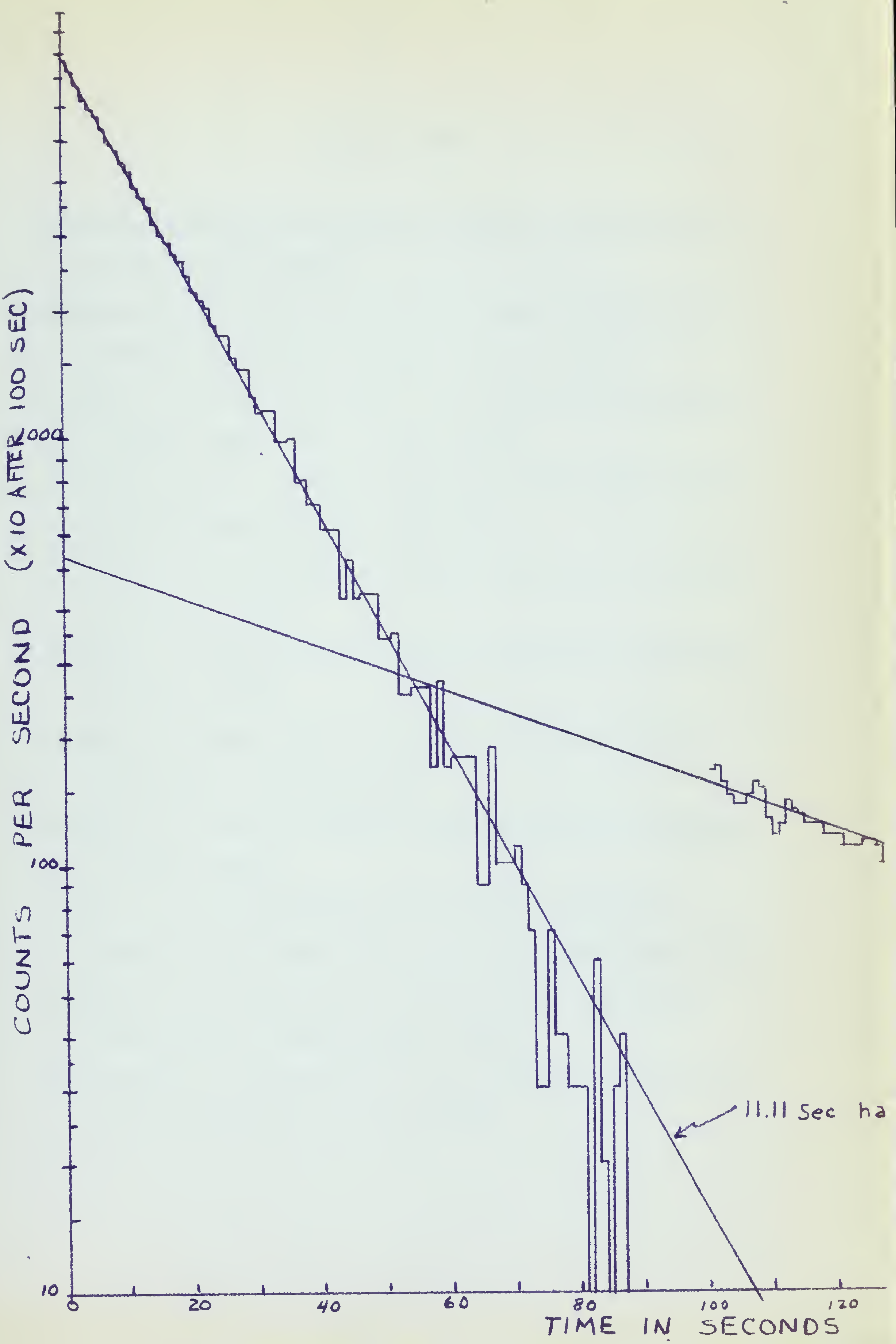


FIGURE 11

ALUMINUM ACTIVITY
WITH BKD AND
WEAK LONG LIVED
ACTIVITY SUBTRACTED

FIGURE 12
MAGNESIUM ACTIVITY
0-100 SECONDS - BKD AND
56.5 SEC ACTIVITY
SUBTRACTED
100-250 SECONDS - BKD
SUBTRACTED AND
COUNTS PER SEC.
AVERAGED OVER
3 SEC. INTERVALS





COUNTS PER SECOND (X10 AFTER 100 SEC)
1000
100
10
0
20
40
60
80
100
120
TIME IN SECONDS
11.11 Sec ha

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